Space Weather Technical Forecast

Issued on Wednesday, 29 November 2023 at 12:47 Local

This technical forecast provides a four day assessment of space weather events. The probabilities stated below are for reaching or exceeding the given levels. For more information about space weather impacts please see the Met Office Space Weather Scales https://www.metoffice.gov.uk/weather/learn-about/space-weather/uk-scales

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Space Weather Forecast Headline: M-flares likely (R1-R2 Blackouts). G1/Minor G2/Moderate Storms likely Days 2-3 (30 Nov-01 Dec) due to CME arrivals.

Analysis of Space Weather Activity over past 24 hours

Solar Activity: Moderate recently, with a M9.9 flare at 28/1950 UTC, from AR3500. This is the most notable and largest of the thirteen visible sunspot regions and is comprised of a compact cluster of dark umbra, most with penumbra. It retains a complex magnetic structure. All other regions on the disc remain smaller and simpler, and either stable or showing signs of decay. There are also a number of filaments on the Earth-facing disc.

The M9.9 flare observed earlier has given a halo CME, which is very likely to be Earth directed, and has been included in the accompanying forecast with an arrival time on Day 3 (01 Dec).

Solar Wind / Geomagnetic Activity: Solar wind speeds have been at slightly elevated winds speeds, initially varying between 410-480 km/s, but have steadied over the past 12hrs to around 430-450 km/s. Density has been around average, dipping below average occasionally. Interplanetary Magnetic Field (IMF), Bt, was weak varying between 3-5 nT, with the north-south component, Bz, also varying weakly. Phi angle was mainly positive (away from the Sun). Geomagnetic activity was Quiet (Kp1-2).

Energetic Particles / Solar Radiation: GOES16 high energy (greater than 10MeV) proton flux remained at background. GOES16 high energy (greater than 2MeV) electron flux has been at Background. The associated 24-hour fluence has remained below the Active threshold (1e8 integrated pfu). The observation at 29/0000 UTC was 3.7e6 integrated pfu.

Four-Day Space Weather Forecast Summary

Solar Activity: Low to Moderate with isolated M-flares (R1-R2 Blackout) considered likely, and a slight chance of an isolated X-class flare (R3 Blackout). The plausible source region being AR3500.

Solar Wind / Geomagnetic Activity: Four earth directed CMEs feature in the forecast. Two of which are most likely to arrive Day 2 (30 Nov), with the third and fourth arriving Day 3 (01 Dec). These CMEs may interact with one another due to their varying velocities, the later faster CME's may catch up and enhance those which left the Sun earlier in the period. Aside from the CMEs, the current slightly elevated solar wind from ongoing influence of CH75, is expected to soon ease to background through Day 1 or early Day 2 (29-30 Nov).

Geomagnetic activity is initially expected to be Quiet (Kp1-2) with a chance of isolated Unsettled spells (Kp3). Multiple fast CME arrivals are likely to bring G1/Minor or G2/Moderate (Kp5-6) geomagnetic storms on Day 2 or 3 (30 Nov or 01 Dec) with a slight chance of G3/Strong storms (Kp7). Geomagnetic activity is then expected to wane into Day 4 (02 Dec) with Quiet to Active

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intervals (Kp1-4) and a slight chance of a G1/Minor storm (Kp5).

Energetic Particles / Solar Radiation: GOES16 high energy proton flux is expected to remain at background levels. There is a slight chance of flux levels approaching or perhaps exceeding the S1 level later in the period as the sunspot region AR3500 moves further west on the visible disc. Electron flux is currently at background, but perhaps trending towards moderate or close to high on diurnal peaks through Day 1 (29 Nov). Any increase is likely to be suppressed again by the CME arrivals. The associated fluence may increase in response, but expected to stay below the Active (1e8 integrated pfu) threshold.

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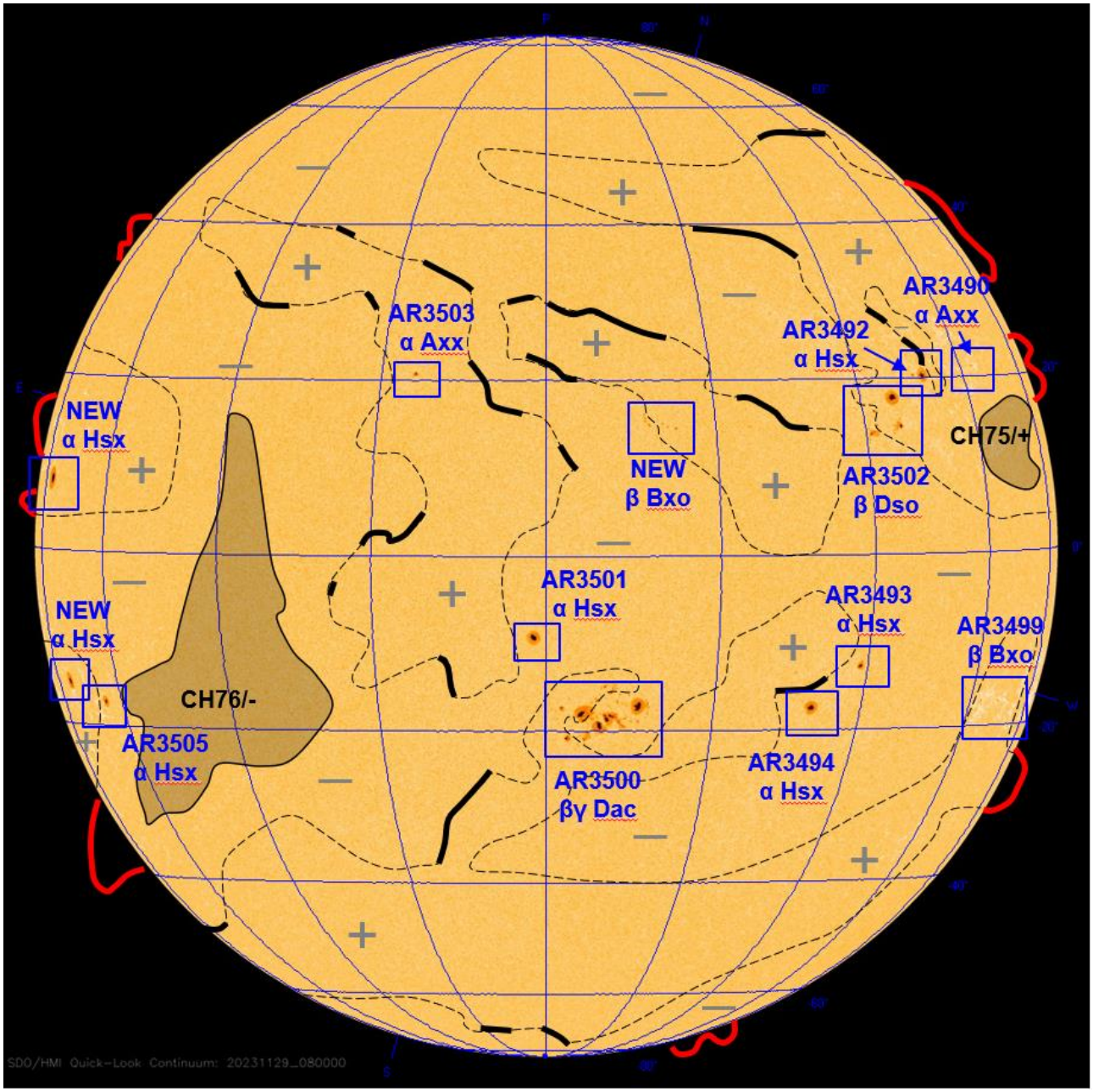
Figure 1. Solar Analysis Valid 29/0800 UTC.



Key: Filament ___ , Prominence ___ , Magnetic Field Line - - - , Polarity +/-, Coronal Holes: Grey shaded area CHxx +/-, Sunspot groups 25xx - Mt Wilson α-β-βγ-βγδ and Zurich-McIntosh Axx etc.

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Geomagnetic Storms:

There are up to four Earth-directed CMEs.

Two glancing impacts are possible on 30 Nov. The first was due to a filament eruption from the southwest disc around 27/0535 UTC off the southwest disc. This has been reanalysed and is forecast to give a glancing impact on Day 2 at around 30/0700 UTC, with the bulk of the material passing beneath Earth. The second is due to a large filament eruption off the northeast disc 27/2340 UTC. This is a faster CME, that is expected to largely miss behind and north of Earth, however there is a potential for a glancing impact later on Day 2 (30 Nov), although this could combine with, and perhaps enhance, the first arrival.

The third is due to a filament eruption from the northeast disc around 27/1840 UTC, coincident with a C6.7 flare from AR3500 in the southeast. A subsequent faint partial halo CME was observed heading southeast. This is more likely to impact Earth than the above eruptions, however this is a slower CME, and not expected to arrive until Day 3, around 01/1800 UTC, although this will likely be swept up by the faster CME mentioned below.

The fourth CME was a large halo CME signature from the M9.9 flare at 28/1950 UTC from AR3500. This has been analysed to have an arrival time at some point early on Day 3 (01 Dec). This CME is very likely to be Earth directed, although there is some uncertainty on its speed, with the latest Enlil model run showing an arrival time around 01/1200 UTC, but if the CME is towards the faster end of solutions then it could arrive earlier, possibly in the late UTC evening of 30 Nov.

Aside from the CMEs solar winds are expected to ease to background through Day 1 or early Day 2 (29-30 Nov) as the influence of coronal hole 75 recedes. No further coronal hole source enhancements are expected.

Geomagnetic activity is initially expected to be Quiet with a chance of isolated Unsettled spells. Multiple fast CME arrivals are likely to bring G1/Minor or G2/Moderate geomagnetic storms on Day 2 or 3 (30 Nov or 01 Dec) with a slight chance of G3/Strong storms. Geomagnetic activity is then expected to wane into Day 4 (02 Dec) with Quiet to Active intervals and a slight chance of a G1/Minor storm due to lingering CME effects.

Geo-Magnetic Storm Probability (Exceedance)	Level	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
Minor or Moderate	G1 to G2	No	10	60	70	20
Strong	G3	No	1	10	20	1
Severe	G4	No	1	1	5	1
Extreme	G5	No	1	1	1	1

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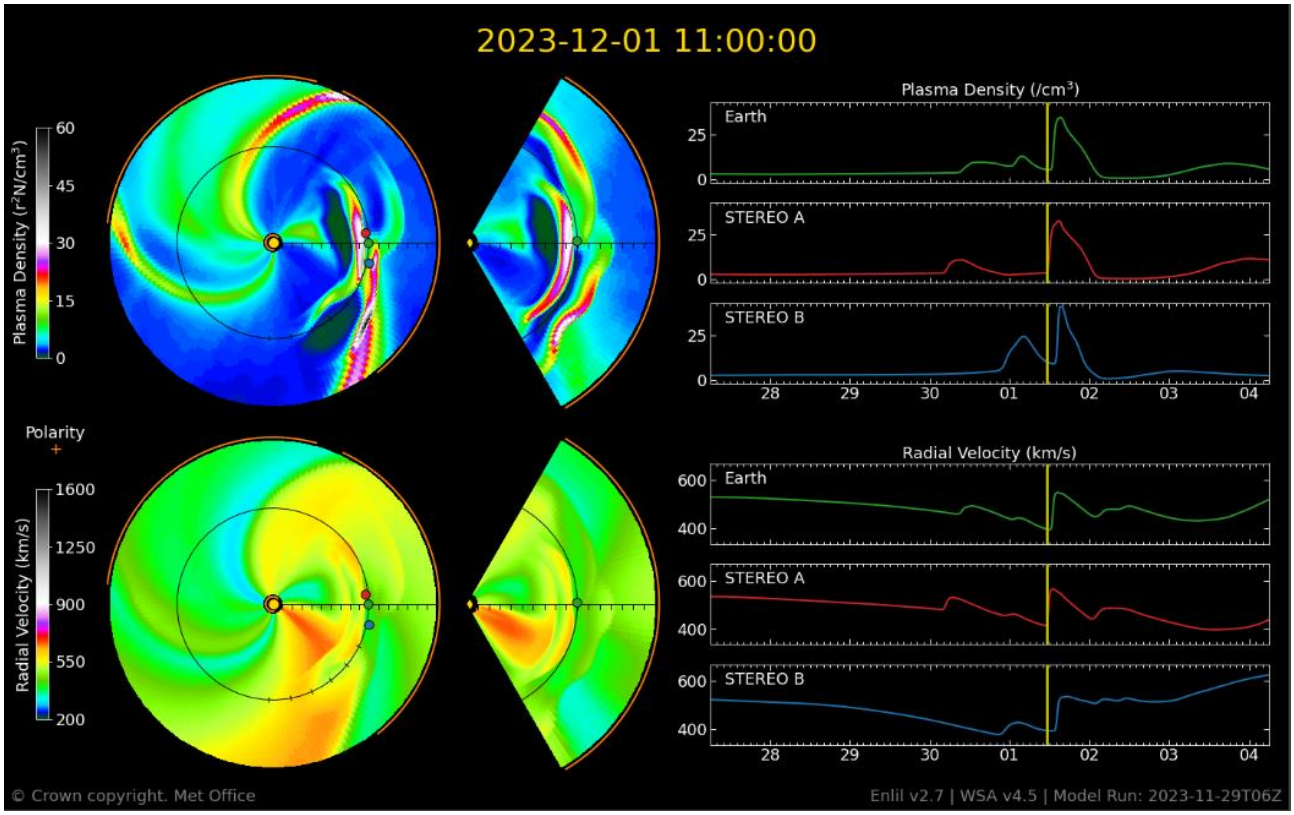
Geomagnetic Activity - Earthbound Coronal Mass Ejections

Date/time 21.5R (UTC)	Halo: Full or Partial	Source	Source Location	Estimated Speed	Estimated Arrival Time	Comments
27/1235	Nil	Filament	SW	575 km/s	Early 30 Nov	Glancing impact
28/0302	Partial	Filament	NE	1040 km/s	Late 30 Nov	Glancing impact. Low confidence
28/0700	Partial	Filament and C6.7 AR3500	NE/SE	380 km/s	Mid 01 Dec	Minimal impact. Likely caught up by faster CME below
29/0056	Full	M9.9 AR3500	S	740 km/s	Early/mid 01 Dec	Likely G1/G2, low chance of G3 if towards faster end of solutions

Figure 2: MOSWOC Enlil showing arrival times of CMEs, and ensemble plot showing various perturbations of CME arrival times



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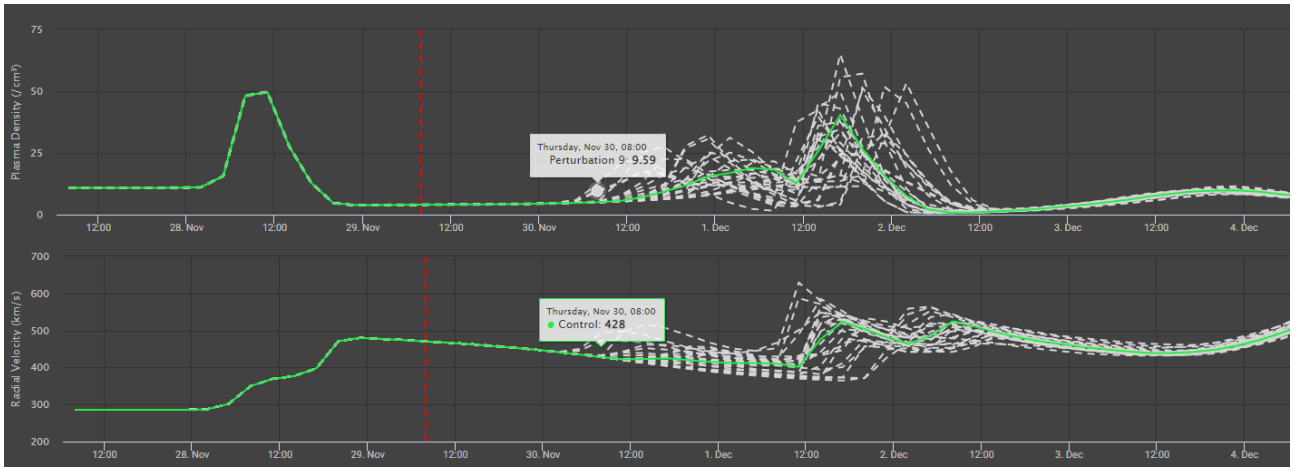

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Radio Blackouts - X-Ray Flares:
Low to Moderate activity is forecast, with a likelihood of isolated M-flares.

There are thirteen sunspots on the disc. AR3500 remains the main region of interest, comprised of a number of compact umbra with surrounding penumbra. However, the previous separation of the positive and negative polarity regions remains, losing its delta configuration but retaining some complexity as a beta-gamma. The other regions remain smaller and simpler. Three unnumbered spots are present on the disk, two having emerged around the eastern limb during the past 24hrs, all seemingly stable at present. Low to Moderate activity is forecast with M-class flares considered likely, and a slight chance of an isolated X-class flare. Should these occur, the most likely source region remains AR3500.

X Ray Flares	Level	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC)	Day 2 (00-24 UTC)	Day 3 (00-24 UTC)	Day 4 (00-24 UTC)
Probability			(%)	(%)	(%)	(%)
Active	R1-R2 M Class	Yes	60	60	60	60
Very Active	R3 to R5 X Class	No	15	15	15	15

Figure 3: GOES 16 & 18 X-ray flux showing M9.9 flare at 28/1950 UTC

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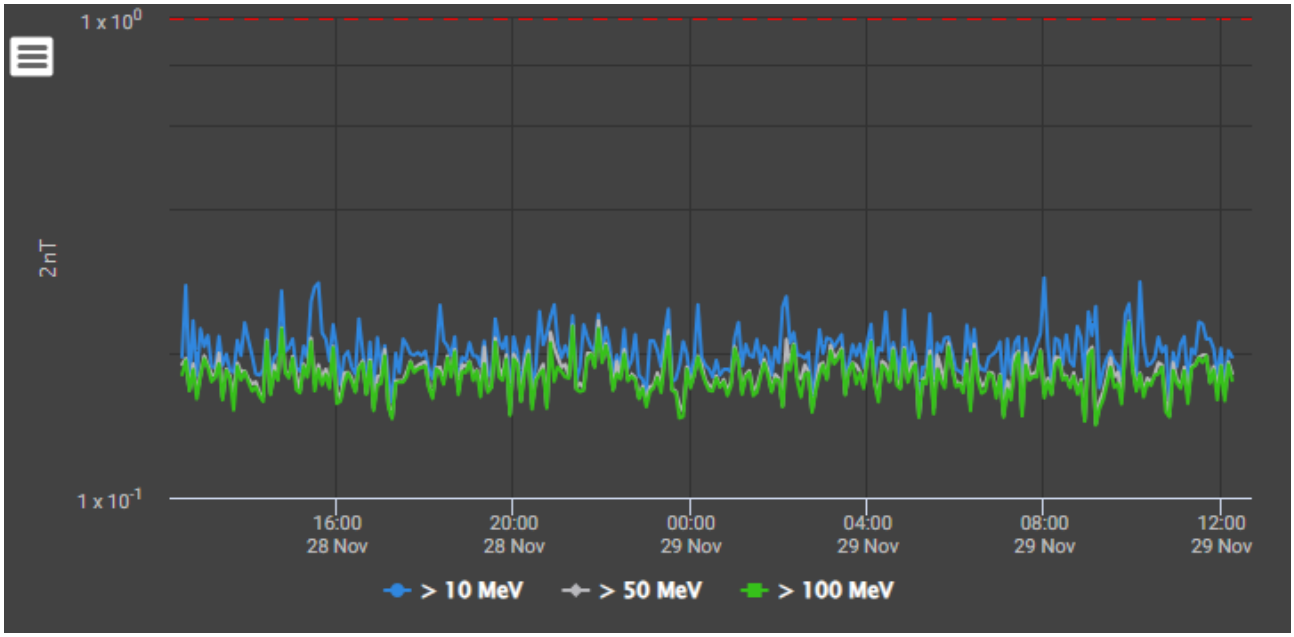
Solar Radiation Storms - (High Energy Protons):
The high energy (greater than 10MeV) proton flux observed by GOES16 is currently at background. There are number of moderately sized sunspot regions on the disc, however the majority of these are magnetically simple mature spots with no significant activity. The main region of note is currently AR3500 in the southeast. This spot gave an M9.8 flare at 28/1950 UTC, although no proton response was observed. As this region moves further westwards there is an increased risk of a proton response from a large flare to be more Earth-directed. There are also a number of filaments on the Earth-facing disc, and large eruptions, especially off the west disc, can result in proton flux increasing at Earth, albeit likely staying below the S1 Minor Radiation Storm level.

Overall this gives a slight chance of elevated protons, increasing slightly on Days 3-4 as AR3500 moves further west on the visible disc.

Radiation Storms Probability (Exceedance)	Level (cm^{-2} sr^{-1} s^{-1})	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
Active	**≥ S1**	No	10	10	15	15
Very Active	**≥ S3 ***	No	1	1	1	1
* S3 ≥ 10 MeV ≥ 1000 pfu and / or ≥ 50 MeV ≥ 10 pfu. (pfu = $cm^{-2}sr^{-1}s^{-1}$)						

Figure 4: GOES 16 Proton flux showing background levels



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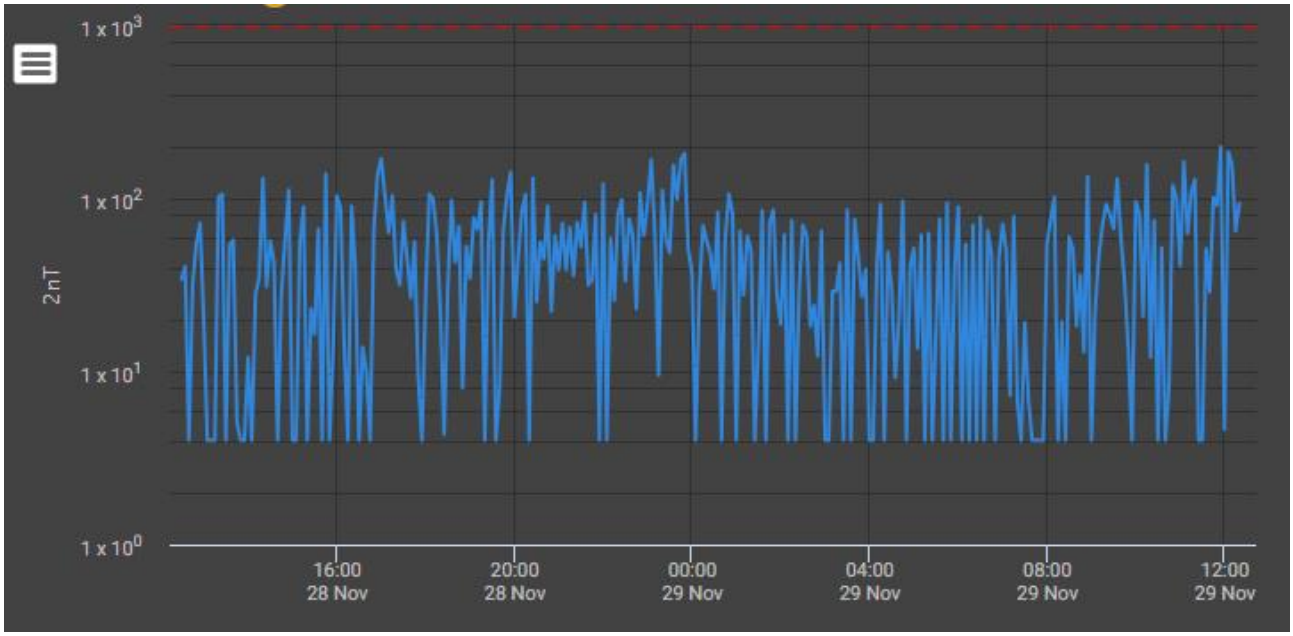
High Energy Electrons Event (≥ 2MeV):

High energy electron flux (greater than 2MeV) as observed by GOES-16 is currently at background in the presence of a slightly elevated solar wind. As the solar wind speed eases through Day 1 (29 Nov) a slight increase in electron flux values is possible, likely rising to moderate levels and potentially to high levels on diurnal peaks. However any increases are subject to the possible CME arrivals from Day 2 onward (30 Nov-02 Dec), which are likely to suppress electrons once again.

Overall electron fluence is expected to remain below the Active threshold (1e8 integrated pfu). This is supported by REFM.

GEO Electron Environment	Level (cm^{-2} sr^{-1} day^{-1})	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC)	Day 2 (00-24 UTC)	Day 3 (00-24 UTC)	Day 4 (00-24 UTC)
Probability (Exceedance)			(%)	(%)	(%)	(%)
Active	≥ 2 MeV ≥ $1x10^8$	No	1	1	1	1
Very Active	≥ 2 MeV ≥ $1x10^9$	No	1	1	1	1

Figure 5: GOES 16 Electron flux and fluence



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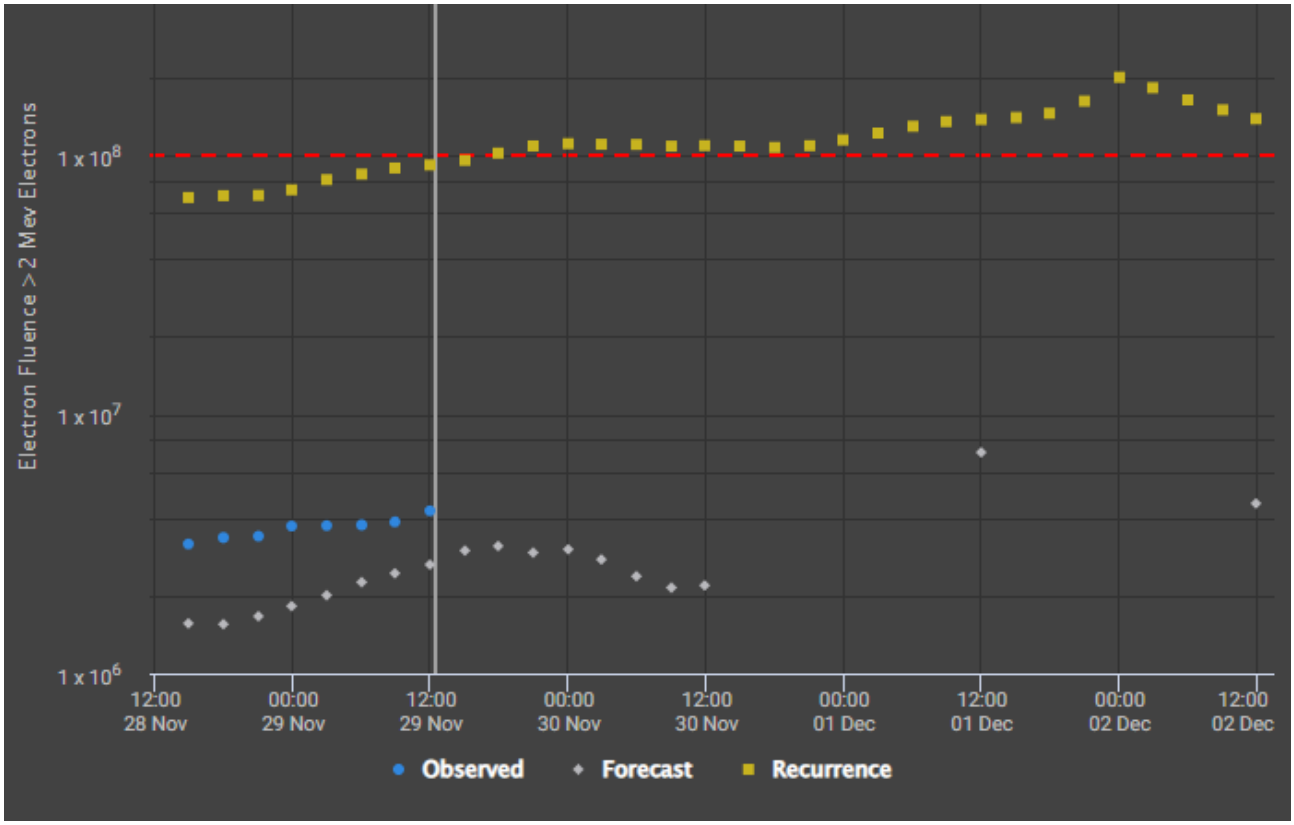

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